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USE OF LIF BY-PRODUCT FOR STABILIZING HYDRAULIC MINE BACKFILL

Report No 88-316-K

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ABSTRACT

A study was undertaken to investigate the feasibility of using a flue gas desulphurization (FGD) by-product from a coal-fired generating station as a binder for hydraulic mine backfill. This by-product was obtained from the limestone (lime) injection into the furnace (LIF) desulphurization process. The strength of a number of specimens stabilized with the LIF material was determined and compared with specimens stabilized with cement. It was found that the strength development of the LIF specimens was slower than that of the cement specimens. At 68% and 65% pulp density, some LIF-stabilized specimens, with percolation rates greater than 10 cm/h, yielded 56-day compressive strength equal to or greater than that of 6% cement-stabilized specimens.

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To Dr. D. Mills
Director of Research

USE OF LIF BY-PRODUCT FOR STABILIZING HYDRAULIC MINE BACKFILL

1.0 INTRODUCTION

As part of Ontario Hydro's effort to reduce acid gas emission from its coal-fired generating stations (GS), the Corporation is studying a number of desulphurization processes. One process which was evaluated at Lakeview TGS in 1986 and 1987 was the limestone (lime) injection into the furnace (LIF) technology/1/. The LIF is a process in which the sorbent (crushed limestone or hydrated lime) is injected directly into the furnace of a coal-fired boiler. The LIF reaction by-product, consisting of fly ash, sulphation by-products and unreacted sorbent, is subsequently removed from the flue-gas stream using fabric filters or electrostatic precipitators. As part of the evaluation program of this process, studies have been or are being done in Ontario Hydro to investigate the handling, disposal problems, as well as the utilization options of the LIF by-product.

One utilization option of the LIF by-product is the use of this material as a binder for stabilizing hydraulic mine backfill because of the self cementitious property of the LIF material. In 1987/88, a research study was undertaken in the Civil Research Department to study the feasibility of using the LIF to stabilize mine backfills. The first part of the study was to conduct a literature review on existing information related to the properties and requirements of stabilized mine backfill. An Ontario Hydro Research Division report/2/ was published as the result of the Part I study. The second part of the study was to conduct laboratory tests to characterize the LIF specimens and to measure the properties of various backfill mixes stabilized with the LIF material. This report will present and discuss the laboratory test data on stabilized backfill specimens.

2.0 BRIEF DISCUSSION ON STABILIZED HYDRAULIC MINE BACKFILLS

Stabilized hydraulic mine backfill has been used in Canada for about 30 years. The stabilized material is similar to a weak concrete and consists of an aggregate (filler) such as mill tailings or sand, a stabilizing agent such as Portland cement and water. In a hydraulic fill, the aggregate is smaller in size than a coarse sand (less than 1.0 mm) with most of the material in the silt to fine sand range (0.01 mm to 0.3 mm). Mine backfills with sand or mill

tailings as an aggregate are usually batch mixed at the ground surface and transported hydraulically to the underground stope area to be filled. The hydraulic transport technique requires a fairly large quantity of water in the mix which is necessary to produce a slurry that is pumpable or will flow due to gravity. When Portland cement (the most common binder for stabilized mine backfill) is used, this high water/cement ratio reduces the effectiveness of the cement and can also cause segregation of the cement and aggregate. However, there are also advantages of this type of hydraulic fill placement; for example, the ease of placement, the ability to get a "tight" fit in the stope and the greater in situ density of the hydraulic fill.

Hydraulic mine backfill stabilized with cement is a great improvement over uncemented fill as it can stand up vertically and be used as a mucking floor, without causing excessive dilution. Cemented fill has the benefits of easy hydraulic placement plus cohesion, two properties that make it an attractive fill type. Portland cement was first used at the time of stabilized fill development because cement was relatively inexpensive and readily available. Portland cement has always performed well as a stabilizing agent; however, the increasing cost of cement has initiated research into ways to reduce Portland cement content, or to replace it with alternative cementing agents. A number of alternative agents, such as natural pozzolans, blast furnace slags and fly ash have been studied for many years with different degrees of success/3,4,5,6/ and the search for new stabilizing materials for mine backfill is continuing.

In this project, a flue-gas desulphurization by-product, called LIF, was tested for its feasibility as a binder for stabilizing mine backfill.

3.0 LIF MATERIAL CHARACTERIZATION

The LIF material was obtained from a pilot-scale LIF process evaluation experiment conducted at the Lakeview TGS in the summer of 1987. Three types of LIF samples were obtained. The first two samples (named LIF-1 and LIF-2) resulted from limestone injection and the third (LIF-3) from hydrated lime injection. Some physical properties of the LIF samples are presented in Table I. All LIF samples exhibited similar particle size distributions with approximately 95% of the material being smaller than 70 μm and about 82% of the grains less than 9 μm in diameter. Grain size distribution for LIF-2 is shown in Figure 1. From X-ray diffraction, all LIF samples contained quartz, mullite, magnetite, alumina-silicate glass, quicklime, anhydrite and calcite; the first four are usual constituents of Lakeview fly ash. The heats of reaction were measured as follows: 40 g of solid LIF material was allowed to react with various amounts of water and the exothermic reaction temperature were recorded over time. The calculated reaction heats for LIF-1, LIF-2 and LIF-3 samples were -50 cal g^{-1}, -54 cal g^{-1} and -63 cal g^{-1} respectively. Williams (1988)/7/ showed that samples consisting of 100% free lime and tested under a similar procedure produced exothermic reaction heat of about -233 cal g^{-1}. Therefore, it was estimated that the three LIF samples contained 21%, 23% and 27% free CaO. Chemical analysis of the LIF samples was also carried out and the results are presented in Table III. Acid digested samples were used for the determination of Ca^{2+}, SO_4^{2-} and CO_3^{2-}. The unburnt carbon content was determined by high temperature thermal combustion and the CaO content by X-ray diffraction. The concentrations of all other elements listed

in Table II were determined by instrumental thermal neutron activation analysis. For comparison, chemical analyses of representative Lakeview fly ash and N.B.S. (National Bureau of Standards) fly ash #1633 are also presented in Table II.

As anticipated, the composition of LIF is similar to that of fly ash with the exception of the high calcium content, which is due to the use of lime or limestone as the sorbent in the scrubbing process. This is reflected in the quantity of free lime in the LIF material compared to that in fly ash (see Table II).

Ontario Ministry of the Environment (MOE) leachate extraction procedure (monofill) was carried out; the results are presented in Table III. Results of Lakeview fly ash are presented for comparison. The current suggested concentration limits for leachate generated by materials considered for use as an unrestricted backfill material in Ontario are also shown in Table III. These suggested limits were derived from the Ontario Drinking Water Objectives: one times the maximum permissible health related objectives and 5 times the maximum objectives based on the aesthetic quality of the water (Golomb, 1986)/8/. From Table III, it follows that the LIF material is within the MOE backfill limits with the exception of barium and chromium which are slightly higher than the suggested maximums. The pH values of leachates (pH = 12.5) can be considered beneficial as they would aid in the neutralization of acidic mine tailings.

4.0 EVALUATION OF LIF AS A BINDER

Stabilized backfill specimens were prepared using either "concrete sand" or Falconbridge mill tailings obtained from Sudbury, Ontario as a filler material. The tailings material is greyish black in colour and has a similar grain-size distribution to a silty sand (Figure 1). In the preliminary testing program, all three samples of LIF were evaluated as the binding materials. For strength comparison purposes, specimens were also formed using 3% Type 10 Portland cement as the binding agent. The pulp density of these specimens was 70% (ie 70% solids and 30% Toronto tap water).

In making a specimen, the mix was poured into a split mold, 5.1 cm (2") in diameter and 10.2 cm (4") in height. A glass plate was placed at the bottom end of the mold and any free water from the mix was allowed to drain from the bottom. Usually, only a few millilitres of free water was lost, because at 70% pulp density, most of the mixing water was used in the slaking of CaO to $Ca(OH)_2$. The prepared specimens were then allowed to cure for 7, 14 and 28 days (100% humidity and 23^{o}C) before testing.

The strength of the test specimens were measured by the standard ASTM uniaxial (unconfined) compression test (ASTM D-2166) and all tests were conducted in triplicate.

The results of the unconfined compression tests (average values) are summarized in Figure 2. The proportions of the mix components are on a dry-weight basis and are identified (eg LIF(L): Tailings (T): Water (W), 1.25 : 1 : 0.96).

The results presented in Figure 2 indicate that:

(1) samples LIF-1 and LIF-2 (limestone sorbent) were stronger binders than LIF-3 (lime sorbent).

(2) for the same mixing proportions, LIF-1 specimens were usually stronger than the LIF-2 specimens, with the exception of the L : T : W (1.25 : 1 : 0.96) mix.

(3) most specimens stabilized by LIF-1 and LIF-2 yielded higher strength than those stabilized with 3% Portland cement. However, it should be noted that a much larger percentage of LIF (the binder) was used in the mix for stabilizing.

Based on the preliminary results, LIF-3 was not as effective a stabilizer as the 3% cement binder. It was therefore decided that further study using this material as a binder was unjustified. However, LIF-1 and LIF-2 both showed potential as binding agents. Owing to budget and time considerations, LIF-2 was arbitrarily selected for the second-phase testing program to gain further appreciation of the behaviour of LIF materials for use as a stabilizing agent.

In order to minimize the number of specimens for strength measurements, results of percolation tests were first performed on a number of candidate mixes. The percolation test was done according to a similar method described by Thomas et al (1979)/3/. In this procedure, the mix is poured into a plastic tube (Ø = 2.5 cm) to a height of 30 cm. A water column of equal height is then placed above the sample giving a hydraulic gradient of 1. The rate of change in the water level is then monitored over time. In preparing the mixes, both 68% and 65% pulp density were used. These pulp densities are commonly used by the mining industry. For comparison purposes, the percolation rates of the 70% pulp density mixes used in the preliminary testing program were measured.

Table IV is a summary of the percolation rate results. As anticipated by the correlation between the amount of LIF in a mix and the increase in compressive strength of the specimen, the percolation rate decreases with an increase in the amount of LIF-2 in the mix. The selection of the mixes for additional strength tests are based on a compromise between the measured percolation rates of the mixes and the anticipated compressive strength of the specimens. The desirable percolation rate of a selected mix should be greater than 10 cm per hour (4"/h), which is recommended for a stabilized mine backfill (Thomas et al, 1979) and the compressive strength of the specimen should be similar to that of a specimen stabilized with 3 to 6% cement, a quantity often used in the mining industry.

A bituminous fly ash from Ontario Hydro's Lakeview GS was used as a component in some mixes. The fly ash is similar to a silt material in grain-size distribution (Figure 1). As indicated in Figure 3, fly ash and a LIF would render compressive strength much higher than these shown in Figure 2.

For the second part of the testing program, cylindrical specimens 7.6 cm in diameter and 15.3 cm in height were used. In preparing the specimens, the free mixing water was not allowed to drain away from the bottom of the

cylindrical mold. This procedure differed from that used in the preliminary testing program. Since this procedure is commonly used by the mining industry in Ontario (Hopkins, 1988)/9/ it was adopted in the second phase of the testing program.

Studies by Mitchell and Wong (1982)/10/ have shown that the strength of stabilized mine backfill specimens depend on the procedure of sample preparation, curing, testing, etc. In the additional laboratory tests, the same procedures were used in preparing and curing the backfill specimens. Therefore, the comparison of the strength data of various specimens is valid.

The strength data obtained from the second phase testing program are summarized in Figures 4 and 5. A number of conclusions may be obtained from these results.

(1) Specimens stabilized with cement displayed higher early strength than other specimens. However, the 56-day strength values were higher for the specimens with binders other than cement. The slow strength development is typical of specimens stabilized with materials containing CaO.

(2) Mixes with tailings gained higher strength than did identical mixes with sand. The differences were more pronounced in mixes containing LIF-2 and fly ash. On the contrary, mixes with tailings had lower percolation rates than sand mixes.

(3) The addition of 1% to 2% cement to the LIF and tailing materials (L : T : C : W mixes) did not seem to improve the early strength development of the specimens. However, the cement did increase the 56-day strength.

(4) As expected, mixes with higher pulp density (ie lower water content) displayed higher strength than those with the same proportions of solid components but lower pulp density (higher water content).

(5) Based on the results summarized in Figures 2, 4 and 5, higher strength for the specimens could probably have been obtained if LIF-1 had been used as the binder.

5.0 CONCLUSIONS

A laboratory research program was undertaken to investigate the feasibility of using a flue gas desulphurization (FGD) by-product from a coal-fired power generating station as a binder for hydraulic mine backfill. Specifically, this by-product was obtained from the limestone (or lime) injection in the furnace (LIF) process.

A number of specimens were prepared and tested for their strength at 7, 14, 28 and 56 days. The results were compared with those specimens stabilized with about 6% Type 10 Portland cement. The comparison of data indicates that, generally, the specimens stabilized with the LIF material, with or without fly ash, show higher 56-day strength than the cement-stabilized specimens.

Limited laboratory data obtained in this study demonstrated that it would be possible to design a hydraulic mine backfill mix stabilized with a LIF material to satisfy the recommended percolation rate of >10 cm/hr. The same mix would also render a 28-day or 56-day strength equal to or greater than that of specimens stabilized with about 6% cement. The slow strength development is characteristic of binding agents containing CaO. Whether or not the slow strength development of the LIF binder is acceptable would depend on the actual strength/time requirements of the stabilized mine backfill at specific underground sites. Hence, it is suggested that the use of the LIF as a binder for mine backfill would need to be studied on a site-specific basis with regard to mixing, placing and strength development.

The leaching characteristics of the LIF was determined to evaluate its environmental acceptability as a binder. Results of the leaching tests (Table III)indicate that the LIF leachate quality for the majority of elements tested is within the suggested Ontario guidelines for backfills. Therefore, it is unlikely that the use of the LIF material as a binder for hydraulic mine backfill would be of significant environmental concern.

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TABLE I

Physical Properties of LIF Samples

Property	Test Method	Lakeview Fly Ash*	LIF-1	LIF-2	LIF-3
% Retained on 45 μm sieve	ASTM C311	11.7	26.4	22.2	26.4
Blaine Fineness [$m^2.kg^{-1}$]	ASTM C204	381	445	426	494
Loss on Ignition at 750^oC	ASTM C311	7.96	9.11	6.73	4.16
Specific Gravity [$kg.m^{-3}$]		2310	2700	2670	2630

*Laboratory composite sample

TABLE II

Chemical Composition of LIF Samples*

Element	NBS** Fly Ash (1633)	Lakeview Fly Ash	LIF-1	LIF-2	LIF-3
Calcium	42 800	25 400	279 000	240 000	277 000
Magnesium	18 325	5 200	20 260	6 600	<3 000
Sodium	3 250	1 300	2 700	2 700	2 600
Potassium	17 600	12 800	7 000	10 000	8 000
Iron		98 400	62 000	89 000	54 000
Aluminum	116 000	118 000	48 700	63 000	60 000
Silicon	C	212 300	C	C	C
Strontium	1 600	1 000	750	840	830
Arsenic	C	76	49	58	36
Barium	3 175	700	370	530	450
Chromium	C	170	83	112	87
Manganese	491	260	140	142	160
Selenium	C	5	7	6	11
Titanium	6 200	C	2 500	3 300	3 200
Uranium	14	7	7	8	8
Vanadium	217	170	127	130	110
CaO (% free)	C	0.34	19	19	27
Carbonate (as CO_3^{2-})	C	C	81 000	57 300	39 500
Sulphate	C	79 800	78 900	61 500	69 300
Unburnt-C	C	C	37 000	32 400	19 600

* all concentrations in μg/g
**average of 2 replicates
C not determined

TABLE III

Leachate Quality

Constituent	Lakeview Fly Ash	LIF-1	LIF-2	LIF-3	Suggested Ontario Guidelines for Backfill Use *
Arsenic (As)	0.03-0.04	<0.001	<0.001	<0.001	0.05
Barium (Ba)	0.5-0.9	2.6	2.6	2.0	1.0
Boron (B)	4.9-9.6	5.1	5.1	2.5	5.0
Chloride (Cl^-)	4-16	57	49.3	46.4	1250
Chromium (Cr)	0.14-0.22	0.1	0.1	0.1	0.05
Copper (Cu)	<0.001	<0.1	<0.1	<0.1	5.0
Iron (toial Fe)	<0.05	<0.1	<0.1	<0.1	1.5
Manganese (Mn)	<0.05	<0.1	<0.1	<0.1	0.25
Nitrate (NO_3^- as N)	0.01-0.34	C	C	C	10.0
Selenium (Se)	0.03-0.16	0.012	0.014	0.009	0.01
Silver (Ag)	<0.001	<0.001	<0.001	<0.001	0.05
Sulphate (SO_4^{2-})	515-986	1400	1250	1120	2500
Zinc (Zn)	<0.02	<0.1	<0.1	<0.1	25
Cyanide (CN^-)	140.02	<0.02	<0.02	<0.02	0.2
PCB	0.0001	<0.001	<0.001	<0.001	0.003
pH	11- 12	12.5	12.5	12.5	-

all concentrations in mg/L
C not done
*Golomb, 1986

TABLE IV

Percolation Rate Measurements on Candidate Mixes

Mix Components (Proportions by Dry Weight)						Pulp Density (%)	Percolation Rate (cm/hr)
LIF-2	Ash	Cement	Tailings	Sand	Water		
1.25			1.0		0.96	70	2.3
1.25			1.0		0.96	70	2.5
1.25			1.0		0.96	70	2.5
		0.05	1.0		0.45	70	12.7
1.0			1.0		0.94	68	3.8
0.6			1.0		0.75	68	4.5
0.5			1.0		0.71	68	7.6
0.4			1.0		0.66	68	8.9*
0.35			1.0		0.64	68	8.9
0.3			1.0		0.61	68	10.2
0.5	0.5		1.0		0.94	68	5.7
0.3	0.3		1.0		0.75	68	6.0
0.25	0.25		1.0		0.71	68	6.1
0.2	0.2		1.0		0.66	68	7.6*
0.15	0.15		1.0		0.61	68	9.1
0.8				1.0	0.85	68	6.4
0.7				1.0	0.80	68	7.0
0.6				1.0	0.75	68	10.2
0.5				1.0	0.71	68	11.2
0.4				1.0	0.66	68	15.2*
0.3	0.3			1.0	0.75	68	9.1
0.25	0.25			1.0	0.71	68	9.9
0.2	0.2			1.0	0.66	68	10.4*
0.15	0.15			1.0	0.61	68	10.4
0.4		0.02	1.0		0.66	68	8.9*
0.4		0.01	1.0		0.66	68	8.9*
		0.033	1.0		0.49	68	22.9
		0.066	1.0		0.50	68	21.6*
1.0			1.0		1.08	65	6.3
0.7			1.0		0.92	65	6.3
0.6			1.0		0.80	65	6.5
0.5			1.0		0.81	65	8.5
0.4			1.0		0.75	65	9.0*
0.38	0.38		1.0		0.94	65	5.7
0.35	0.35		1.0		0.92	65	6.4
0.30	0.30		1.0		0.86	65	7.6
0.25	0.25		1.0		0.81	65	10.0
0.2	0.2		1.0		0.75	65	10.8*
0.7				1.0	0.92	65	8.6
0.5				1.0	0.81	65	10.8
0.4				1.0	0.75	65	12.4*
0.35	0.35			1.0	0.92	65	9.2
0.30	0.30			1.0	0.86	65	9.6
0.25	0.25			1.0	0.81	65	10.0
0.2	0.2			1.0	0.75	65	12.0*

*mixes selected for strength measurements

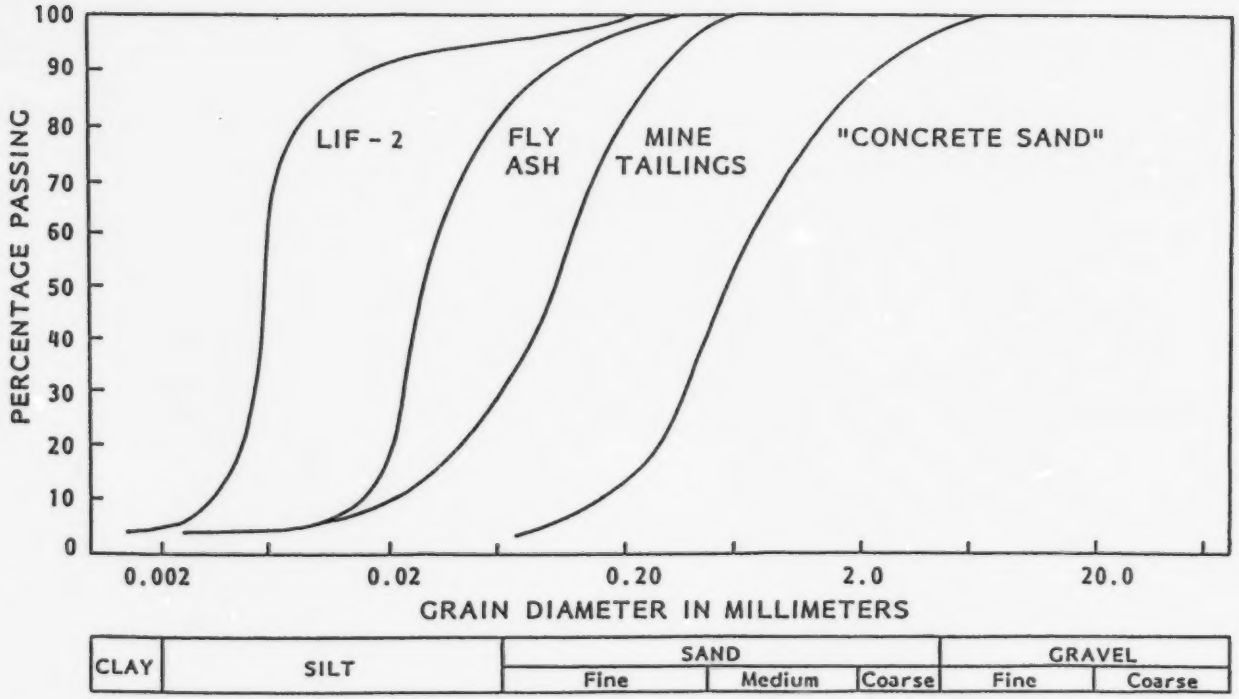

FIG. 1 GRAIN-SIZE DISTRIBUTION OF SAND, TAILINGS, FLY ASH AND LIF-2

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178824-RD

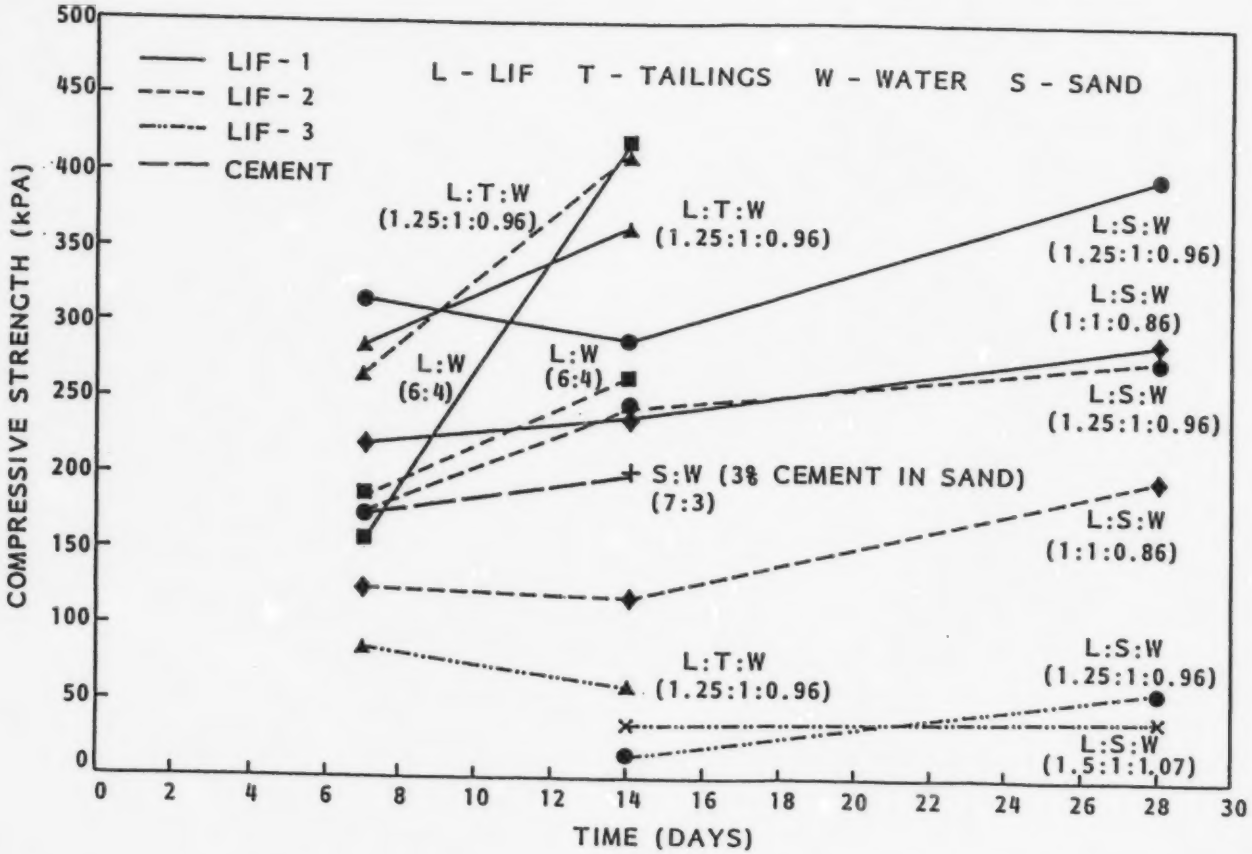

FIG. 2 PRELIMINARY STRENGTH DATA OF STABILIZED SPECIMENS AT 70% PULP DENSITY (EXCEPTING TWO SPECIMENS OF LIF AND WATER AT 60% PULP DENSITY)

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178825-RD

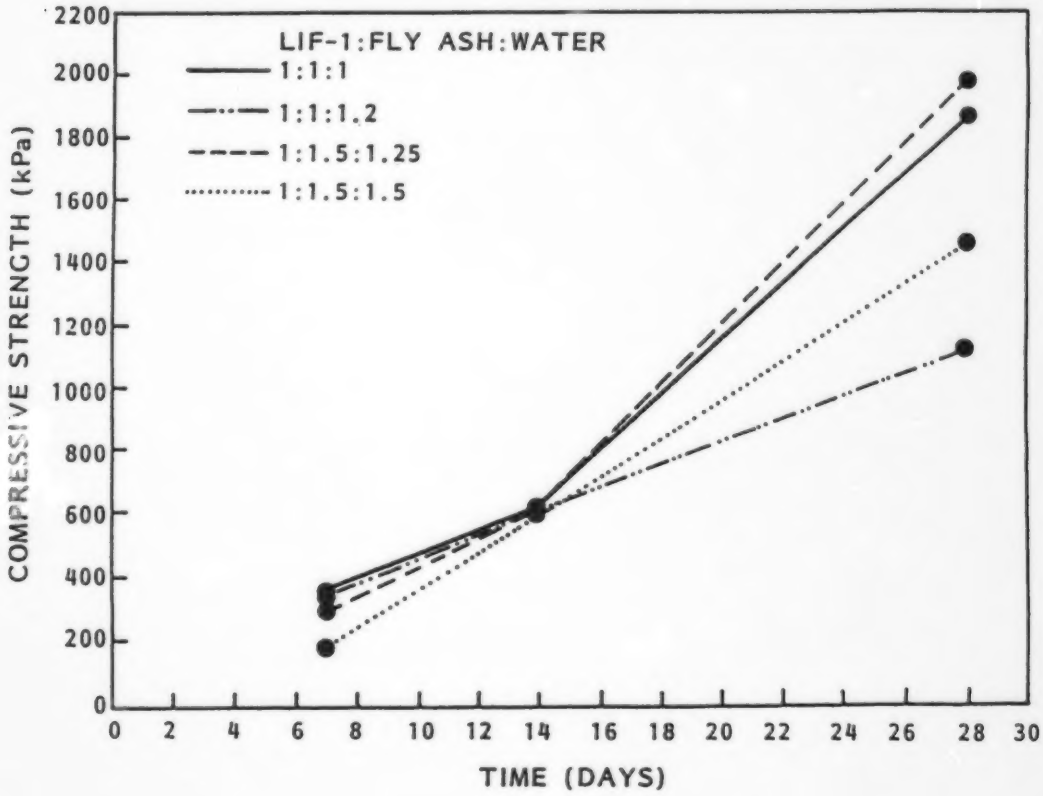

FIG. 3 COMPRESSIVE STRENGTH RESULTS OF SPECIMENS MADE OF LIF-1, FLY ASH AND WATER

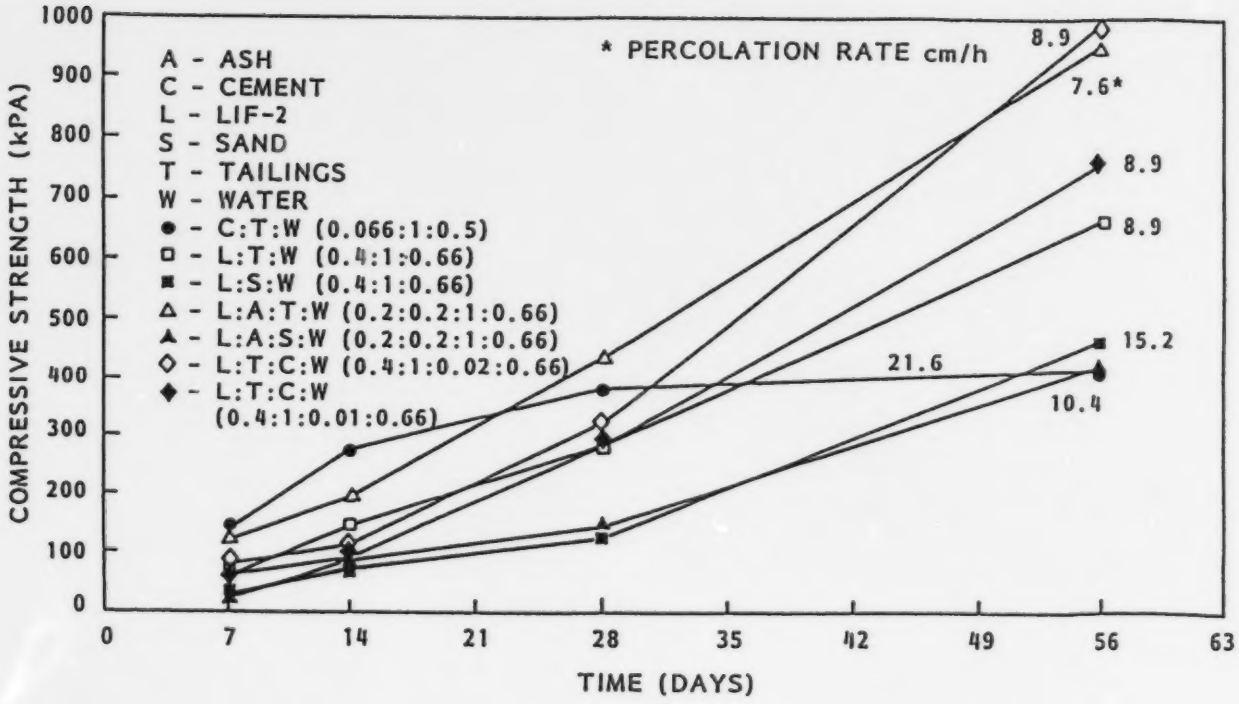

FIG. 4 COMPRESSIVE STRENGTH RESULTS OF STABILIZED SPECIMENS (PULP DENSITY = 68%)

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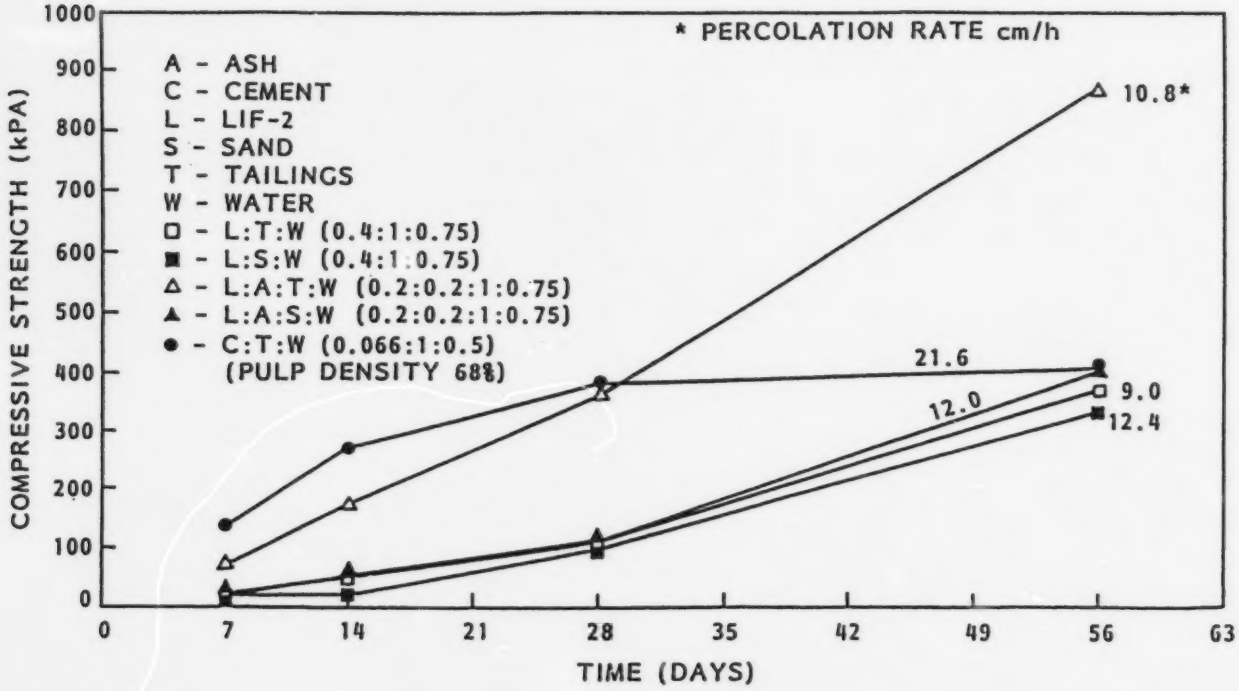

FIG. 5 COMPRESSIVE STRENGTH RESULTS OF STABILIZED SPECIMENS (PULP DENSITY = 65%)